Note on the Solar Constant and the Apparent Temperature of the Sun. By M. C. Féry, D.Sc.

(*Communicated by Sir David Gill, K.C.B., F.R.S.*)

The *Solar Constant* is the quantity of heat received by the Earth in calories per sq. cm. per minute, correction being made for the atmospheric absorption.

The *Apparent Temperature* of the Sun is that which a perfectly black body would have, which produced the same intensity of radiation, with the same apparent diameter as the Sun.

It is unnecessary to insist upon the importance of the determination of the solar constant; it is from the Sun that we derive, more or less directly, all the various forms of energy that we see transformed around us. Hence we have a large number of different types of actinometers which aim at measuring the solar constant or recording its variations. In principle they all contain a body exposed to the radiation, and which is termed the *receiver*, this body being covered with a substance of high absorbing power. Differences in detail exist in the mode of measuring the energy absorbed by the receiver. In those instruments which may be termed *calorimetric*, the rise of temperature of the receiver, of which the mass and specific heat are known, enables the energy received to be easily calculated (Pouillet, Violle, etc.).

In the more recent, so-called, *compensation* actinometers, the idea has been to balance the effect of the solar radiation falling on one of the junctions of a thermopile by an electric current, which imparts to the other junction a definitely known number of watts (Knut Ångström).

Measurement of the Solar Constant.

One of the greatest difficulties in this measurement lies in the evaluation of the atmospheric absorption. It is in fact to the doubt which exists as to the value of this correction that we may attribute the greater part of the enormous range ($A = 1{\cdot}5$ to 4) obtained in the measurements. The general consensus of opinion at the present day is in favour of taking A as 2·4.

Measurement of the Solar Temperature.

Before the exact law of radiation was known, observers were content to extrapolate various formulæ for evaluating the temperature of the Sun. Terrestrial measurements made for determining the coefficients in these formulæ rarely dealt with temperatures exceeding 1000° C. It is not astonishing, therefore, that inexact formulæ extrapolated from these low temperatures gave rise to values varying between 1500° and several millions of degrees.

It is, however, the figures above the probable mean apparent

temperature (5360° C.) which are the most numerous in these early determinations. This remark also applies to high temperatures in general; platinum, for instance, has seen its melting-point lowered from 2000° C. to 1730° C. in a few years.

This exaggeration is due to the intensity of the physiological sensation caused by bodies at temperatures above 1400° C. The retinal sensation produced is also a function of the general illumination of the room occupied by the observer, as it depends upon the *aperture of the pupil*; it depends also largely upon the dimensions of the hot body, as its temperature, measured by the scale of Pouillet, appears lower as its size is reduced. Who would have imagined the temperature of carbon filaments to be as high as 1700° or 1800° C. before the measurements of le Chatelier?

Applications of Stefan's Law to Astronomy.

About 1880 Stefan enunciated for the first time the *exact* relation which exists between the temperature of a body and the energy which it radiates, and a few years later the law of the fourth power was theoretically demonstrated in the case of a black body by Boltzmann.

Wilson was the first who introduced the idea of applying the Stefan-Boltzmann law

$$Q = a\,(T^4 - t^4)$$

to the study of the apparent temperature of different points of the Sun's surface. Until then this investigation had only been made by *photometric measurements of luminosity* which showed a certain lack of precision, in common with all other physiological measurements. Wilson received the radiation of the Sun upon one of the junctions of a Boys radiomicrometer, and that from an electric furnace upon the other junction. By varying the opening of the furnace and its distance, the deflection could be reduced to zero, indicating the equality of the two intensities of radiation. This method has some analogy to that of Ångström, but should be still more rigorous, as it compares the sources of energy *in the same form*.

Wilson obtained 5286° as the mean temperature by direct measurement. The correction of 29 per cent. which he applied to this value, assuming a coefficient of zenith transmission of ·71, gave him 5773° C. as the temperature measured outside the limits of the atmosphere.

A value of from 7000° C. to 10,000° C. is, however, accepted for the mean temperature. Poynting has made the following remark on this subject:* "This [Wilson's] is no doubt too low a value. Either, then, Wilson's zenith transmission was less than 71 per cent., or Kurlbaum's constant is too small."†

* *Phil. Trans. Roy. Soc.*, 1903, vol. 202 A.

† This latter hypothesis of Poynting's was correct as I have shown. *Comptes Rendus*, 5 Avril 1909, t. cxlviii. p. 915.

Since this time I have applied the Stefan law to the measurement of the highest temperatures used in industry, and more than 700 instruments based on this principle are actually in use. They are composed in principle of a gilded mirror which concentrates the total radiation of the furnace upon the minute junction (1 to 2 mm. in diameter) of a thermocouple. A portable galvanometer graduated in millivolts and in temperatures is employed for the measurements.

M. Millochau and I have thought that an instrument of this kind, suitably modified, would easily permit of the study of different parts of the solar surface. The junction of the thermocouple has been still further reduced in size (·5 mm. diameter) and the focal length of the mirror increased to 1 metre, which gives a solar image of 8 mm. diameter.

A sector-shaped diaphragm permitted the deflections to be reduced in a known ratio. The instrument was calibrated upon an electric furnace and upon the crater of an arc.

More than 750 observations made by M. Millochau at different altitudes, from Meudon to the top of Mont Blanc, and at different zenith distances on the summit, have led to fixing the coefficient of zenith transmission at the latter station as ·91.

The temperature at the centre of the Sun's disc with this correction was found to be 5550° C. absolute, and the mean temperature 5360°.

This apparatus having been acquired by an Indian university, was completely restandardised at the National Physical Laboratory. The deflections were found to be exactly proportional to the fourth power of the absolute temperature between 1600° C. absolute and the temperature of the arc. Being directed at Teddington upon the Sun on a very clear and dry day, it gave as the mean of eight concordant determinations 5153° absolute at the centre of the Sun's disc.

The coefficient of zenith transmission at Teddington therefore on this day must have been $\left(\frac{5153}{5550}\right)^4 = \cdot 74$, or the absorption 26 per cent.

In calculating the mean temperature of the Sun from the accepted solar constant of 2·4, and by the aid of the corrected Stefan constant ($\sigma = 6\cdot 3$),* we obtain

$$T_m^4 = \frac{2\cdot 4 \times \dfrac{4\cdot 16}{60}}{6\cdot 3 \times \tan^2 \dfrac{\phi}{2}} \qquad \text{whence } T_m = 5920°.$$

* C. Féry, *Comptes Rendus*, 5 Avril 1909. I have determined this constant by means of an actinometer provided with a perfectly absorbent receiver. Preliminary experiments had shown me that the platinum black employed by Kurlbaum only absorbed 82 per cent. of the radiation from a body at 100° C., which this author had employed as the source of radiation; he thus obtained a value of $\sigma = 5\cdot 32$ watts, which is too low by 18 per cent.

This temperature is certainly too high; it would give a dominant wave-length according to Wien's displacement law, $\lambda_m \theta = 2940$, of $\lambda_m = \cdot 496\,\mu$, which is in the blue region of the spectrum.*

Conversely, we can calculate the solar constant from the mean solar temperature which M. Millochau has obtained on Mont Blanc, viz. 5360°.

We thus find

$$A = 6{\cdot}3 \times 5360^4 \times \tan^2 \frac{\phi}{2} = \cdot 1125,$$

or in small calories per minute

$$\frac{\cdot 1125 \times 60}{4{\cdot}15} = 1{\cdot}65.$$

These considerations appear to show that the accepted solar constant is too high. This result is doubtless due to an exaggeration of the atmospheric correction; it may also be partially attributed to the fact that existing actinometers are all covered with substances having a selective absorption (lamp black or platinum black).

It would be of importance to investigate the best form for an actinometer to obtain complete absorption, and to repeat the simultaneous measurements of T_m and A, with a pyrometric telescope and a perfectly absorbing actinometer.

* The mean apparent temperature of the Sun calculated by the displacement law would be $\frac{2940}{0{\cdot}54} = 5440$ absolute, adopting the value $0{\cdot}54\,\mu$ for λ_m as found by Langley.

Erratum in Mr. Knobel's paper on a Chinese Planisphere.

Page 438, line 5, *for* Mas *read* Mao.